Performance Results of Miniature Cs D1 CPT Atomic Clock

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OBJECTIVE

Develop a **new atomic oscillator** that

① is significantly **smaller** than our previous generation

and

② is **smaller** than and has **better stability** than the existing state of the art.

Comparison: Size & Stability

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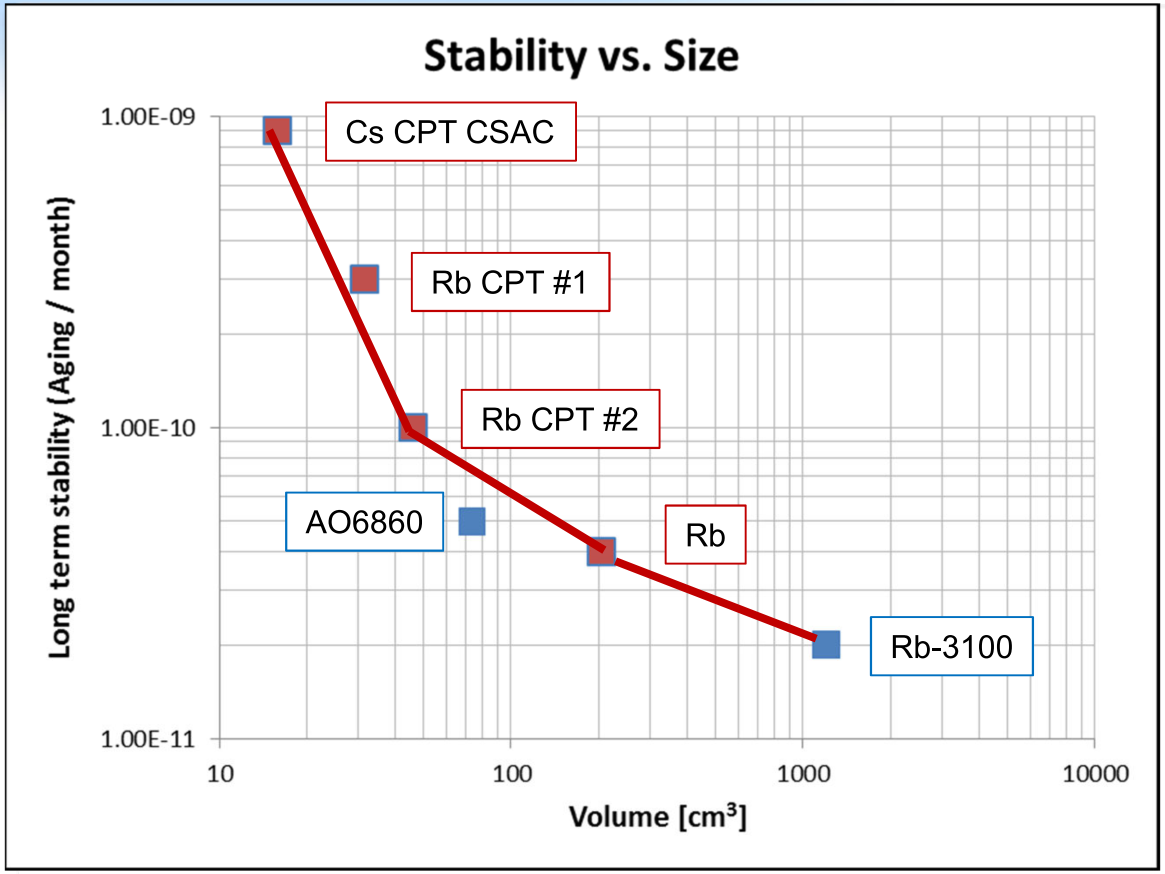


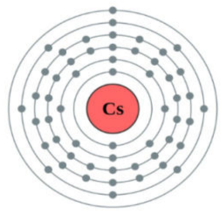
smaller
and
better stability
than existing
state-of-the-art

	Existing State of the Art					This Work
	Cs CPT CSAC	Rb CPT #1	Rb CPT #2	Rb	Epson Rb3100	Epson AO6860
Size (cm^3)	16	32	46	203	1204	73
Aging/mo (max)	$9e^{-10}$	$3e^{-10}$	$1e^{-10}$	$4e^{-11}$	$2e^{-11}$	$5e^{-11}$

TECHNOLOGY

How did we build this?

Technology Overview – Basic Principles

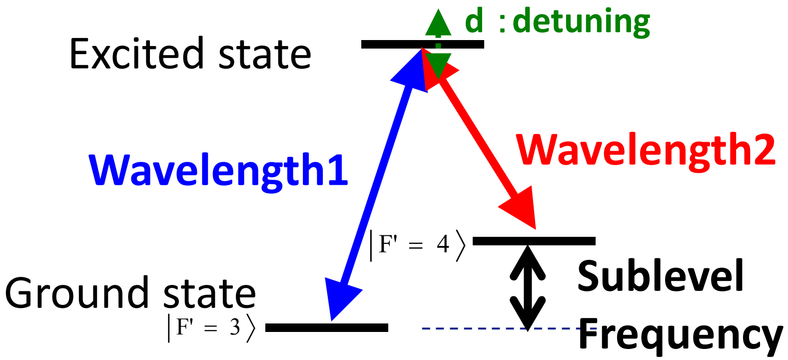


- Coherent Population Trapping
- Cæsium D1 Transition
- Many components made by Epson
  - VCSEL (Vertical Cavity Surface-Emitting Laser)
  - TCXO (Temperature-Compensated Crystal Oscillator)
  - Physics Package
  - Synthetic Quartz
  - ICs
- Size: 18 (H) mm x 60 (W) mm x 68（D）mm

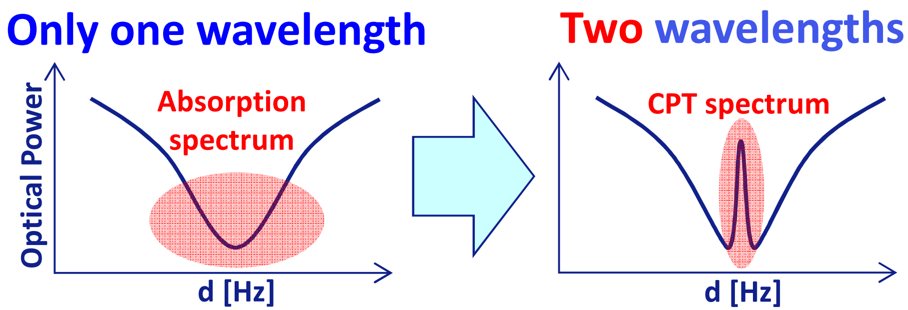
Coherent Population Trapping (CPT)

Select one Sublevel Frequency of Cs.

Advantage： Laser enables Miniaturization

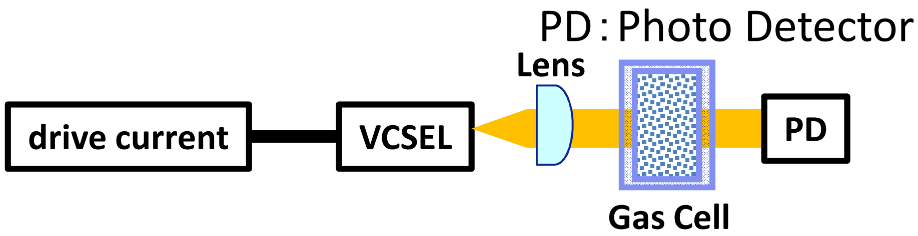


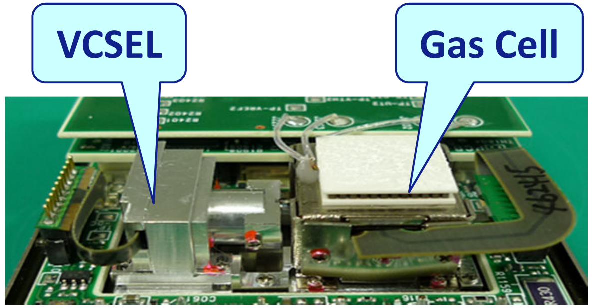
for Cs
Sublevel Frequency = 9.2 GHz



Basics
1. **Resonance with Cs**
2. **Two Wavelengths (9.2GHz difference)**
3. **Frequency difference sweep**

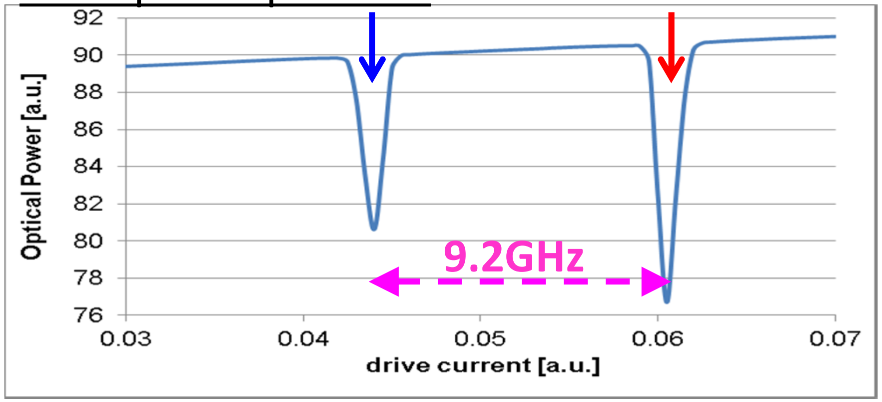
Step 1: Establish Resonance with Cs





- We use a VCSEL as a light source.
- Temperature of the VCSEL and gas cell are controlled.
- By sweeping the VCSEL drive current:
  - we can sweep laser wavelength.
  - and measure absorption.
- We adjust laser wavelength to around 894nm, and observe two absorption spectrum (AS).
- The difference between the two AS is 9.2GHz.

Absorption spectrum



Step 2: Modulate Laser with RF

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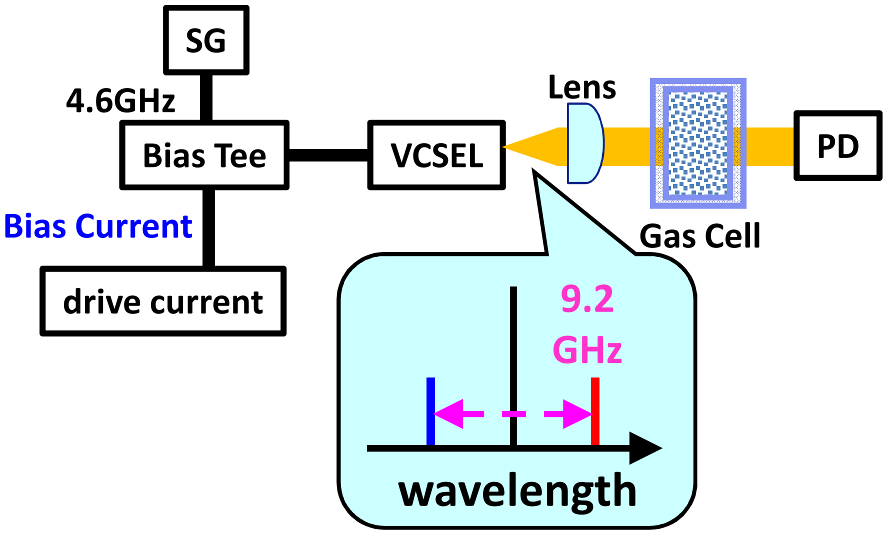
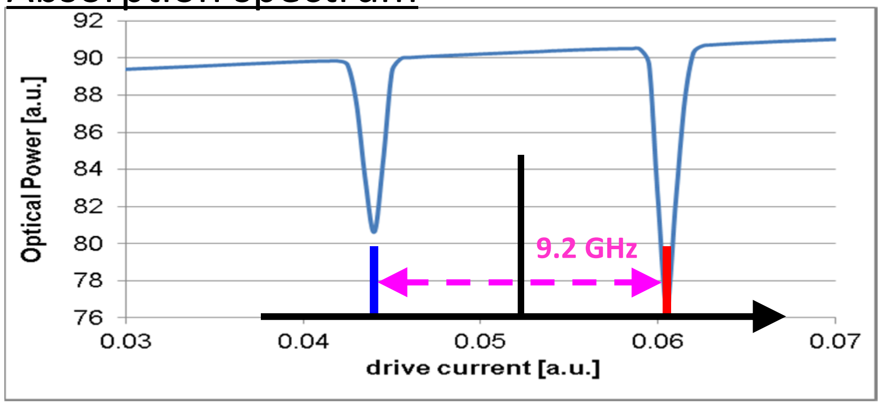


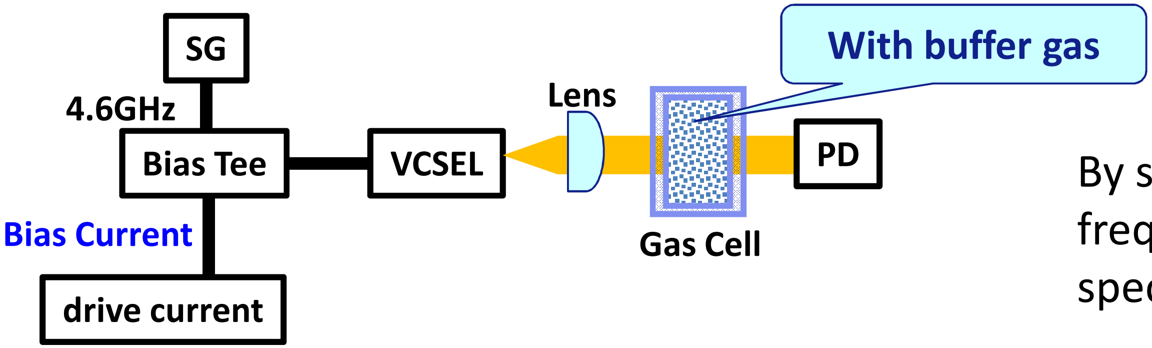
A 4.6 GHz signal
creates two laser spectra
which are 9.2GHz apart.

We modulate the laser
by changing the drive current
to get two wavelengths.

Absorption spectrum

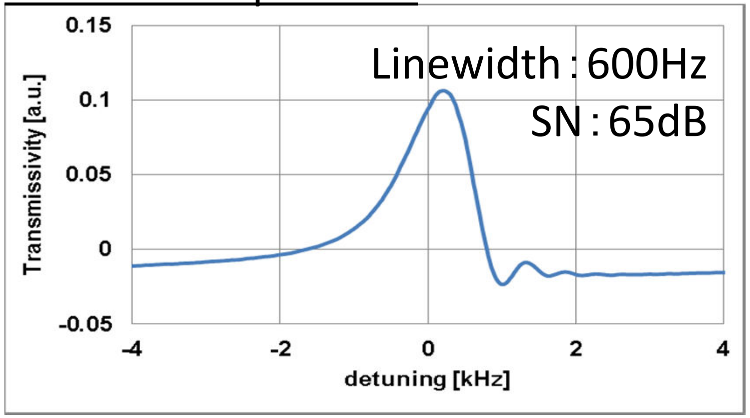


Step 3: Sweep Frequency



By sweeping 4.6GHz microwave frequency, we can get CPT spectrum.

EPSON CPT spectrum



- CPT spectrum affects short term stability.
- A narrow and strong peak is best.

$$short\ term\ stability = \frac{A}{SN} \times \frac{Linewidth}{9.2GHz}$$

- We mix buffer gas in gas cell for better short term stability.

Block Diagram of the Atomic Oscillator

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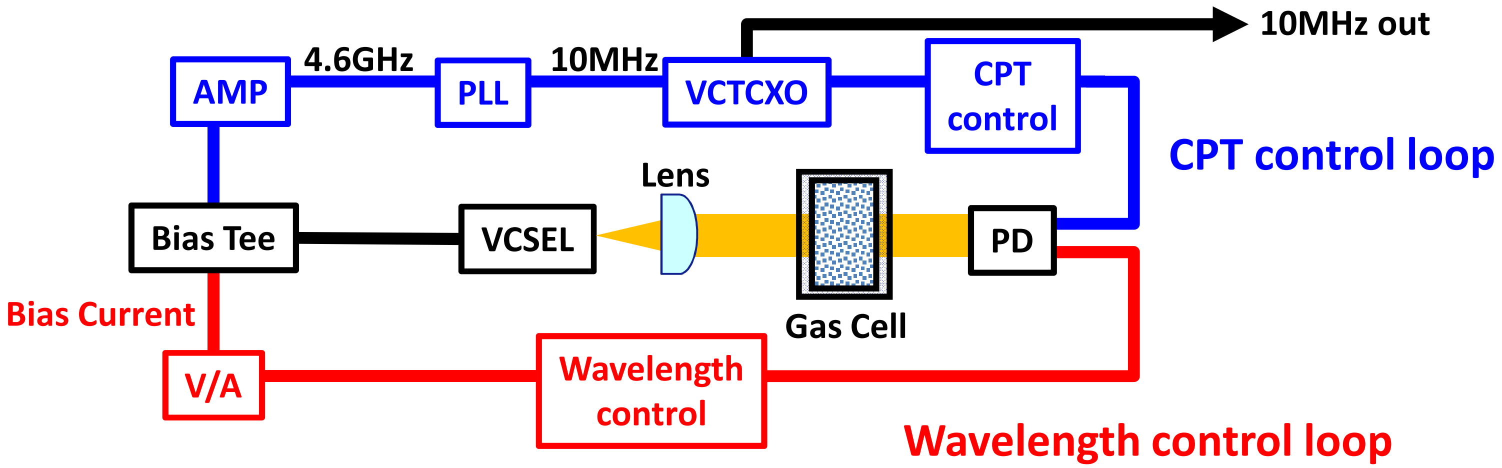
CPT control loop

- Controls modulation to match the CPT spectrum.



Wavelength Control Loop

- Adjusts VCSEL bias current to center the wavelength.

Both loops are controlled by one IC.

How did we achieve better accuracy?

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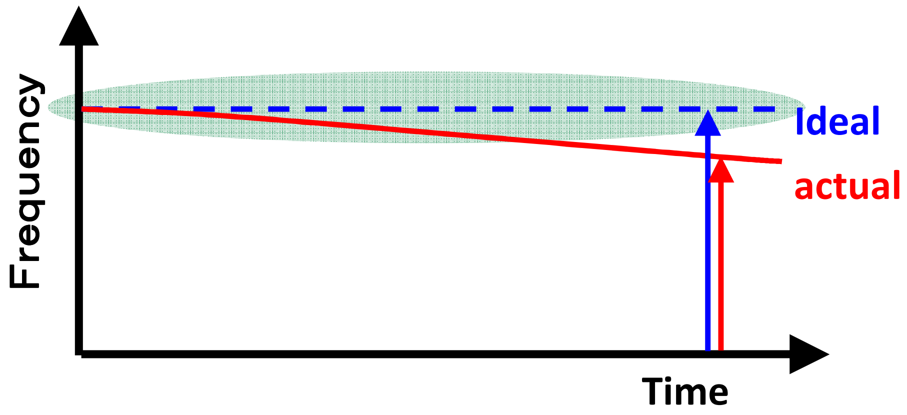
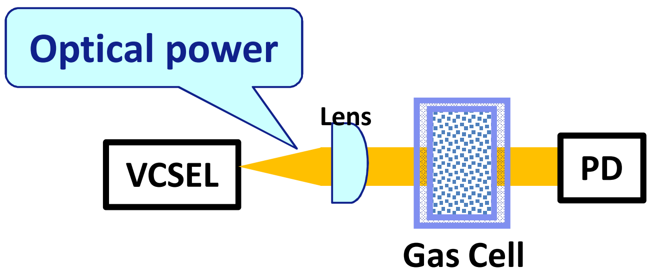


About Aging

Good aging
⇒merit : maintenance free
⇒target : 5e-11/month

Change of Physical material (in particular optical power) causes:



[parameter about optical power]

①Laser wavelength
 ～Along with change of wavelength,
 drive current changes laser power.
②Transmissivity
③4.6GHz microwave power ～bigger sensitivity

Error Budget

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Affect frequency parameter

（Parameter aging）×（Sensitivity）

⇒The influence is reduced.

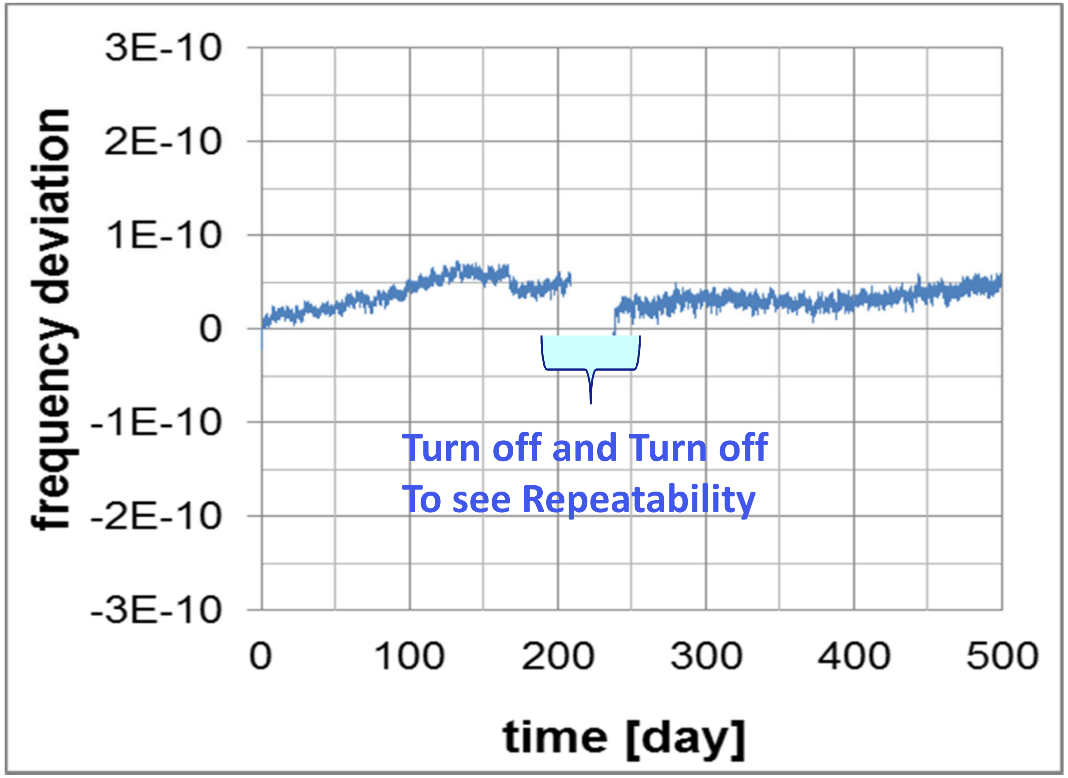
Parameter	aging /month
① Laser Wavelength	**+6E-12**
② Transmissivity	**-1E-11**
③ 4.6 GHz Microwave power	**±1E-11**

SUM:-1.4E-11～+6E-12
⇒All parameters are reduced,
and the aging characteristic is achieved.

MEASURED DATA

1. Long-Term Stability (Aging)
2. Short-Term Stability (Allan Variance)
3. Warm-Up Time
4. Temperature Stability
5. Phase Noise

Long-Term Stability (Aging)



Points for Long-Term Stability (Aging):

- **Laser wavelength**
- **Transmissivity**
- **Microwave power**

Target
< ±5E-11/month

Short-Term Stability (Allan Variance)

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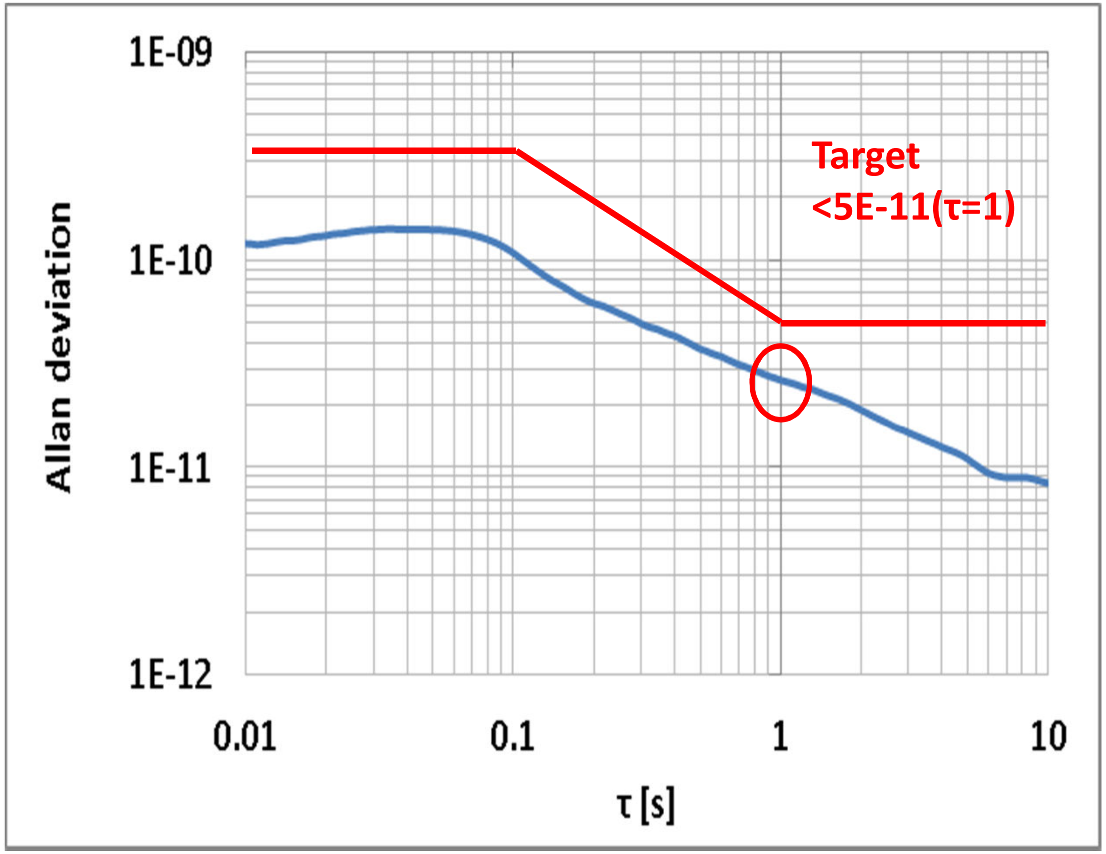

Points for Short-Term Stability:

- **Cell Scale**
- **Buffer gas pressure**
- **Optical power**
- PLL CN
- Loop gain

Warm-Up Time

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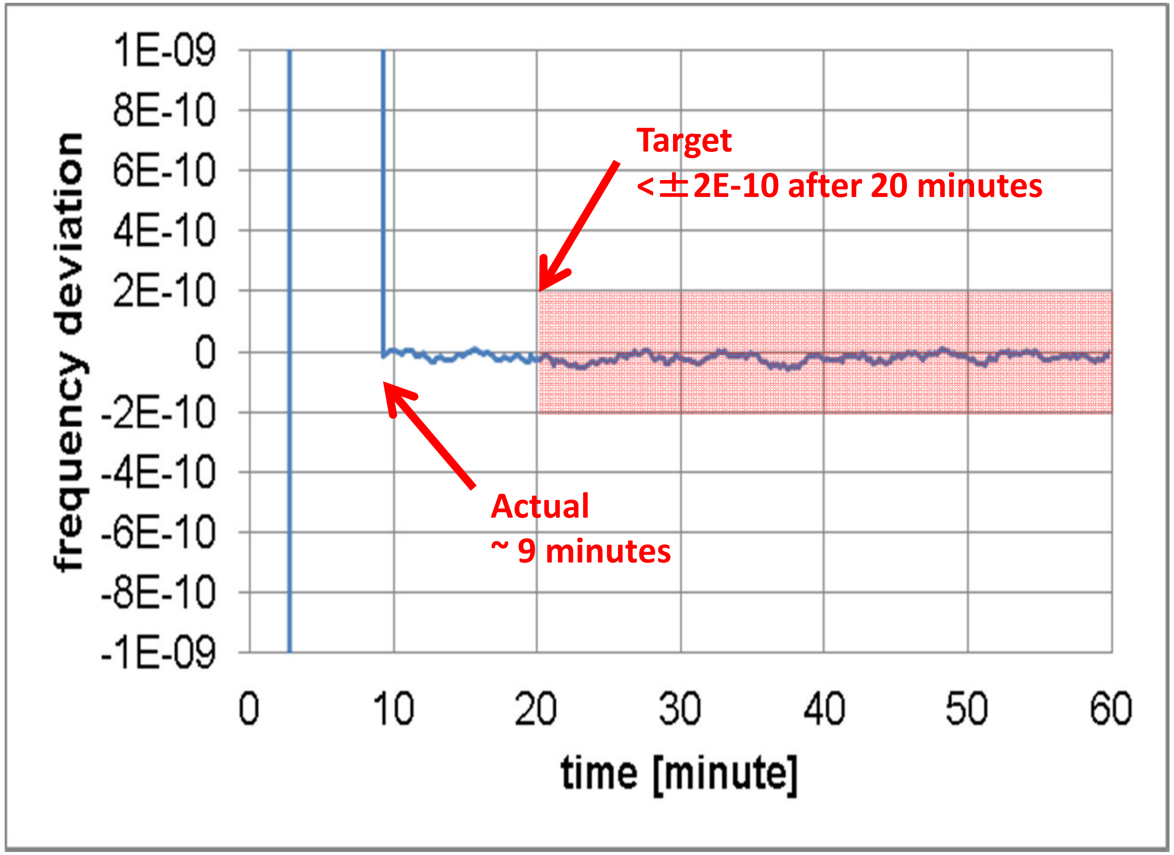

Points for Warm-Up:

- **Temperature control loop**

Temperature Stability

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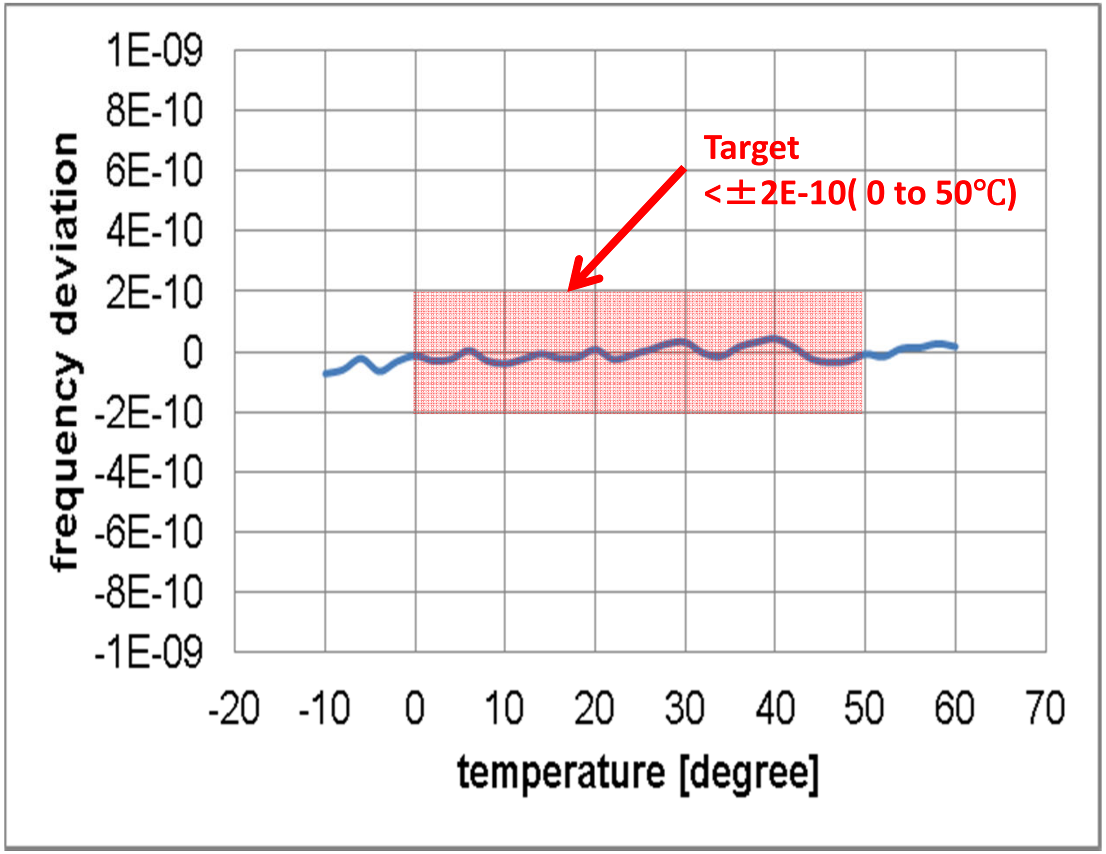
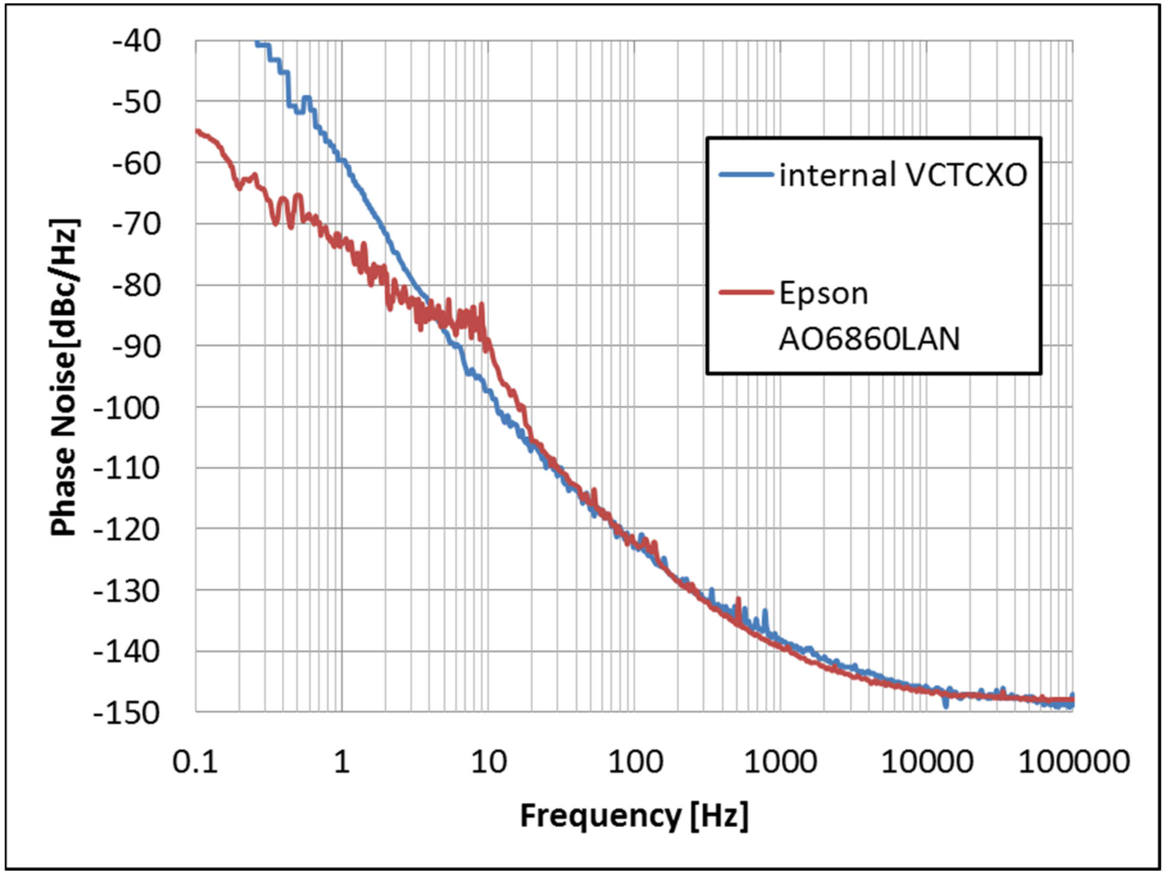


Points for Temperature Stability:

- Cell temp stability
- VCSEL temp stability
- Mixed buffer gas

Phase Noise



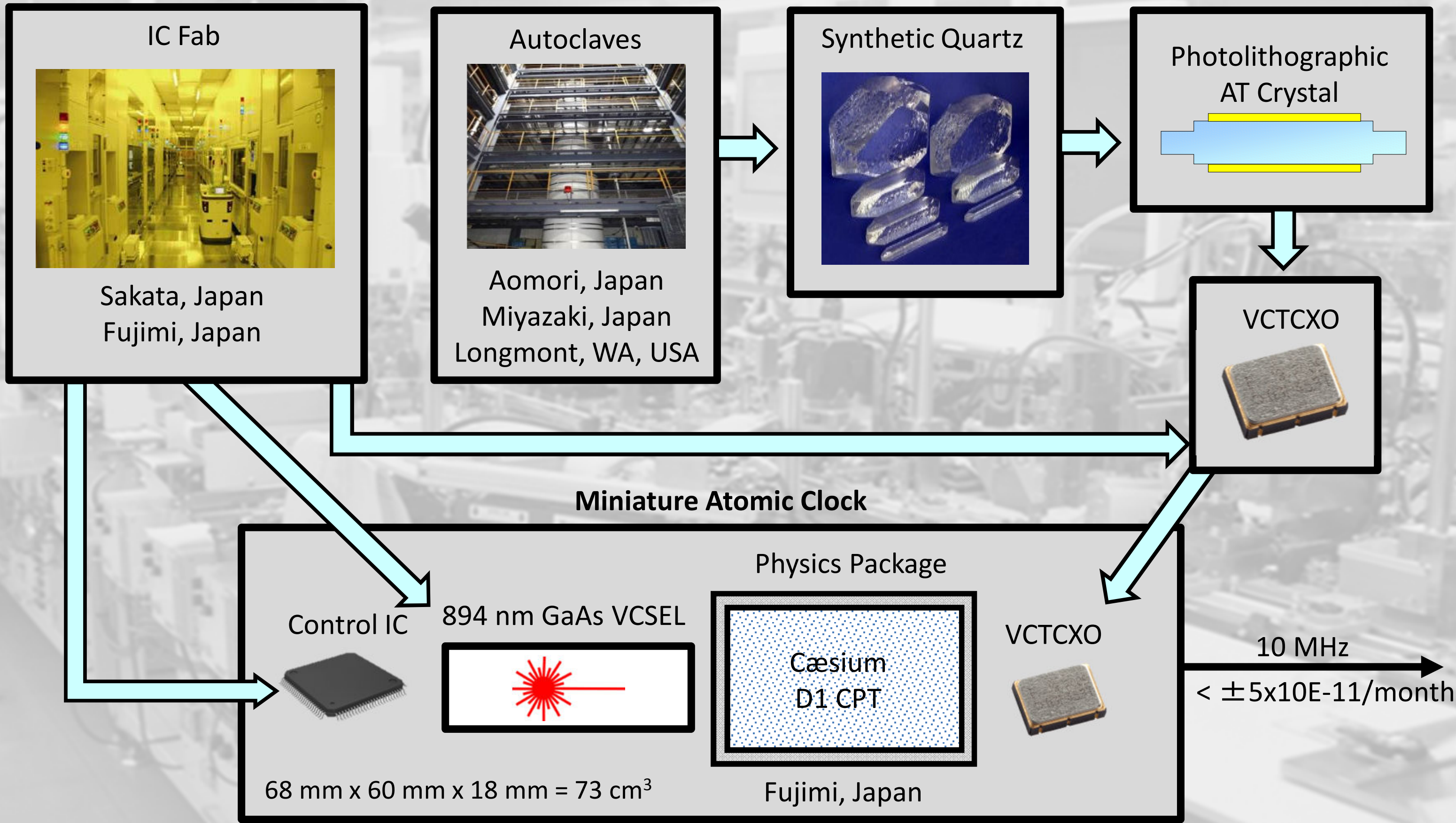
Points for Phase Noise:

- Gas cell determines phase noise below the PLL loop bandwidth
- Local oscillator determines phase noise above the PLL loop bandwidth
- Cut off frequency is 10Hz

SUMMARY

- Technology
- Performance Achieved

Technologies Used in Miniature Atomic Clock



Performance Achieved

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Parameter	Target	Typical	Units
Stability			
Long-Term	< ±5x10E-11	±2.5x10E-11	per month
Short-Term (τ=1)	< 5x10E-11	2.5x10E-11	
vs. Temperature	< ±2x10E-10	±0.5x10E-10	
Warmup (200 ppt)	< 20	9	minutes
Temperature	0 ~ +50 -10 ~ +60		° C
Supply			
Voltage	3.3		V
Power (operating)	3	3	W
Power (turn-on)	20	20	W
Dimensions	68 x 60 x 18		mm


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Thank You!!!
EPSON
Micro Atomic Oscillator
AO6860LAN
10MHz
Input DC +3.3V
Parts Code X1C000011
Yasuo “Mario” Maruyama